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SRNL PARTICIPATION IN THE MULTI-SCALE ENSEMBLE EXERCISES

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Consequence assessment during emergency response often requires atmospheric transport and dispersion modeling to guide decision making. A statistical analysis of the ensemble of results from several models is a useful way of estimating the uncertainty for a given forecast. ENSEMBLE is a European Union program that utilizes an internet-based system to ingest transport results from numerous modeling agencies. A recent set of exercises required output on three distinct spatial and temporal scales. The Savannah River National Laboratory (SRNL) uses a regional prognostic model nested within a larger-scale synoptic model to generate the meteorological conditions which are in turn used in a Lagrangian particle dispersion model. A discussion of SRNL participation in these exercises is given, with particular emphasis on requirements for provision of results in a timely manner with regard to the various spatial scales.

I. INTRODUCTION

Prognostic atmospheric dispersion models are used to generate consequence assessments, which assist decision-makers in the event of a release from a nuclear facility. Differences in the forecast wind fields generated by various meteorological agencies, differences in the transport and diffusion models themselves, as well as differences in the way these models treat the release source term, all may result in differences in the simulated plumes. The European Union sponsors the ENSEMBLE project as administered by the Joint Research Centre in Ispra, Italy which provides techniques which may be used to enable atmospheric modelers to provide decision-makers with a more realistic understanding of how both the atmosphere and the models behave. Traditionally, the focus for ENSEMBLE has been on long-range transport and dispersion consequence assessment at relatively coarse spatial resolution. Potential modeling strengths and weaknesses may be discerned by examining results from an ensemble of model simulations, and ENSEMBLE has conducted over two dozen exercises, as well as required model output for the European Tracer Experiments conducted in late 1994. A recent set of exercises required results at the traditional spatial resolution, as well as at much finer grid spacing.

The Savannah River National Laboratory uses a regional prognostic model nested within a larger scale synoptic National Centers for Environmental Prediction (NCEP) model to generate the meteorological conditions which are in turn used in a Lagrangian particle dispersion model. Use of these types of models is advantageous in generating the necessary atmospheric detail for fine scale simulations. However, providing results to decision-makers in a timely manner during an actual emergency can be problematic. A discussion of SRNL participation in these exercises is given here, with particular emphasis on the requirement for providing results in a timely manner for the various spatial scales.

II. ENSEMBLE BACKGROUND

The ENSEMBLE program is an extension of previous multi-national modeling efforts conducted in Europe following the Chernobyl accident in an effort to better understand short and long-range transport and dispersion effects in the event of a hazardous atmospheric release. In ENSEMBLE, a web-based system has been implemented to allow for easy dissemination of model results[1].

SRNL has participated in numerous planned exercises, as well as several special exercises relating to previous European multi-national modeling efforts. Required output includes 'instantaneous' concentration [Bq/m^3] as averaged over the previous hour at five different levels above ground (0, 200, 500, 1300, and 3000 m), cumulative surface concentration [Bq/m^3], integrated wet and dry deposition [Bq/m^2], and cumulative precipitation [mm].

Traditionally, the exercises required results on a (relatively coarse) grid of 0.5 deg (~50 km) horizontal spacing covering all of Europe as well as parts of western Asia (~7500 km × 4500 km) at a time-interval of 3 hours up to roughly 60 hours after the initial release. An added complexity for the series of exercises discussed here is that results were required at differing spatial and temporal scales.

III. MODEL BACKGROUND

III.A. Prognostic Numerical Model

The Regional Atmospheric Modeling System (RAMS, version 4.3[2]) is a three-dimensional, finite-difference numerical model used to study a wide variety of atmospheric motions. It is used routinely by SRNL for regional and local forecasts often in a nested grid configuration. Basic features of the model include the use of non-hydrostatic, quasi-compressible equations and a terrain-following coordinate system with variable vertical resolution. A terrain-following vertical coordinate system allows for the incorporation of topographic features.

Larger-scale meteorological data are used to generate initialization files in RAMS as interpolated to a (polar-stereographic) model grid. The initialization file in RAMS corresponding to the starting time in the simulation is then used to create an initial condition for the entire three-dimensional RAMS model grid. A Newtonian relaxation scheme is used to provide lateral boundary conditions by driving (nudging) the prognostic variables toward the forecasted large-scale values using linear interpolation in time[3]. Data for these simulations come from the National Oceanic and Atmospheric Administration (NOAA) Global Forecast System (GFS) model with ~95 km grid spacing and forecast information at 3-hr intervals. The coarse grid spacing used in the current RAMS configuration is 60 km, but does not cover the extreme periphery of the standard ENSEMBLE domain.

III.B. Stochastic Transport Model

A Lagrangian particle dispersion model (LPDM[4]) is used in this study for stochastic transport calculations. Three-dimensional winds and turbulence (Gaussian) fields from RAMS are used as input for LPDM. Numerical solution of the Langevin stochastic differential equation for subgrid-scale turbulent velocities[5] and subsequent tracking of a large number of particle positions allows for calculation of concentration and deposition. The results are interpolated to the ENSEMBLE grid where available. Points not covered by the RAMS grid are assigned missing values.

IV. APPLICATION

A series of exercises from March 2007 involved a hypothetical release of three separate species from Pyrzyce, Poland (15.0ºE, 53.0ºN) at 02 UTC, 06 March. Results were required on the standard grid for one of these exercises (Exercise #022) out to 12 UTC, 08 March. However, two other temporal and spatial scale results were also required. Consequence assessment results on a finer grid (0.2 deg, Exercise #023) covering a smaller area centered at the release location were required at 1-hr intervals up to 24 hours (02 UTC, 07 March) after the initial release, while an extremely fine grid (0.02 deg, Exercise #024) centered at the release at 1-hr intervals up to 6 hours (08 UTC, 06 March) after the release was also required. The domains for the required results are depicted in Fig. 1. Note that the outer domain encompasses the spatial region for all previous standard ENSEMBLE exercises.

SRNL conducts daily simulations for the outer region at 60-km horizontal grid spacing and 1-hr time intervals using RAMS. The transport results are then generated on a concentration grid at half the RAMS grid spacing (30 km). This procedure was used for the initial forecast product sent in to ENSEMBLE for Exercises #022 and #023. The results were sent within two hours of notification.

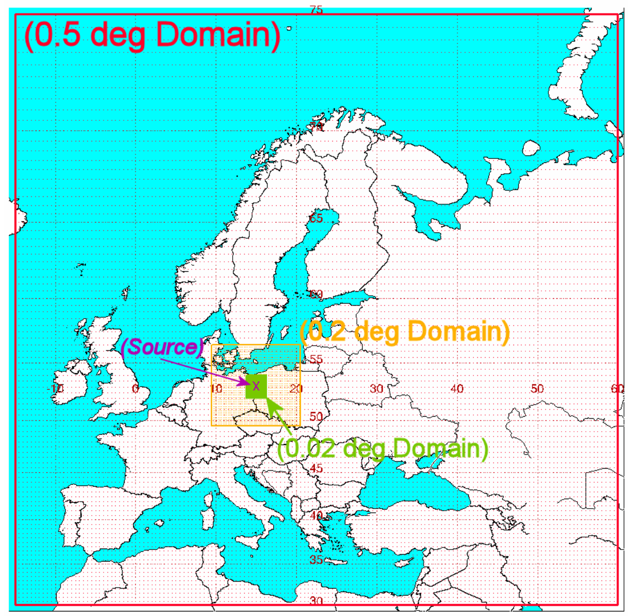


Figure 1: Domains of varying spatial size for ENSEMBLE exercises of 06 March, 2007.

However, due to the very fine spacing required for Exercise #024, a separate simulation had to be conducted using nested grids centered about the release point. For this problem, two grids of 15-km and 3.75-km horizontal grid spacing were generated at 15-minute intervals for the required 6-hr duration. The transport results from LPDM were then generated at a concentration grid spacing of 1.5 km. After interpolation to the ENSEMBLE grid, these results were sent roughly 8 hours later. A summary of the grid characteristics and timing is given in Table I. Note that another set of simulations for the coarser grids were conducted after available observations were incorporated into the larger-scale data (termed “analysis” in Table I).

V. RESULTS

A very powerful tool in ENSEMBLE is the agreement on threshold concentration. A threshold value is selected and the percentage of models predicting values above this threshold for a given time is plotted for the entire domain space.

Figure 2 illustrates this for two different thresholds of integrated concentration at a time of 12 UTC, 08 March.

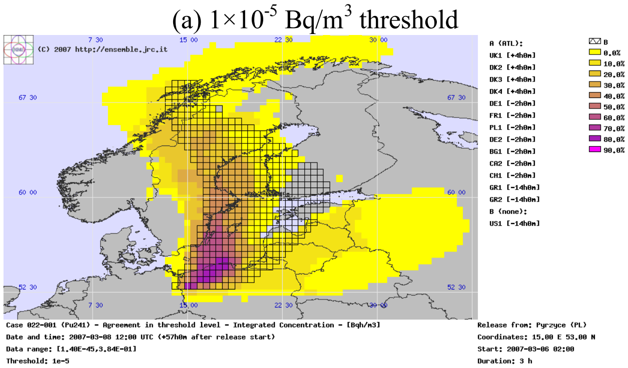
TABLE I: Simulation Details for Each of the Three Exercises.

	#022 (0.5 deg)		**#023 (0.2 deg)**		**#024 (0.02 deg)**	
	Forecast	**Analysis**	**Forecast**	**Analysis**	**Forecast**	**Analysis**
Simulation Length (hr)	72	66	72	33	×	15
Number of RAMS grids	1	2	1	2	×	3
RAMS grid spacing (km)	60	60,15	60	60,15	×	60, 15, 3.75
Conc Grid Spacing (km)	30	30	30	15	×	1.5
Results Supplied (T + hr)	2	78	2	28.5	×	<u>*8.5*</u>

T: Time in which SRNL was notified (~3 hours after initial electronic notification sent from ENSEMBLE).

Thirteen other model runs (UK1, DK2, DK3, etc.) are shown versus the SRNL forecast simulation (US1, crosshatched) for a release of ^{241}Pu. The effluent spreads north and east from the source over the Baltic Sea and is predicted to affect Belarus, Lithuania, Latvia, Estonia, Ukraine, western Russia, as well as the Scandinavian countries. For the higher threshold (1×10^{-5} Bq/m^3) it is evident that the majority of the models predict a more northerly track, while a couple of the models predict the plume to spread more to the east-northeast. The SRNL result generally takes a northward route, although the plume is further east at its midpoint than the other model results. For the lower threshold (1×10^{-8} Bq/m^3) the SRNL results lie within the predictions of the other participants.

(a) 1×10^{-5} Bq/m^3 threshold



(b) 1×10^{-8} Bq/m^3 threshold

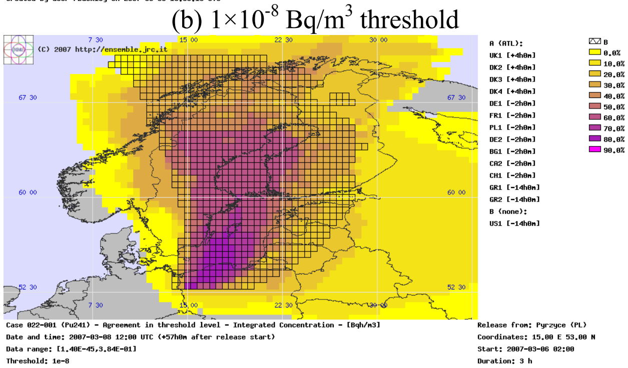


Figure 2: Agreement for integrated concentration for a release of ^{241}Pu for thresholds of (a) 1×10^{-5} Bq/m^3 and (b) 1×10^{-8} Bq/m^3. Results are valid at 12 UTC, 08 March. Colors denote differing percentages of model agreement.

For the fine-grid exercise (#024), a comparison of integrated surface concentration for three models is shown in Fig. 3 at the final required time (08 UTC, 06 March). The spatial distance is much smaller here, with the plume impacts predicted to be confined to the northern portion of Poland. Of interest here is the difference in the plume projections for the three selected models. While all plumes indicate general transport to the east-northeast, the SRNL plume (US1) exhibits higher surface concentrations over a larger area, the GR2 plume is very narrow, and the UK1 plume appears to fall somewhere between the other two.

VI. DISCUSSION/CONCLUSIONS

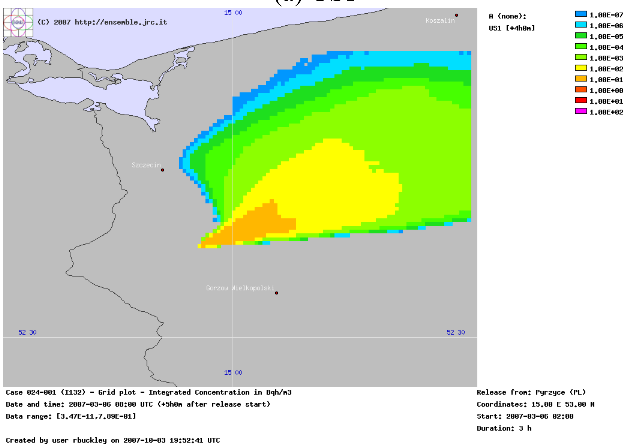
The ENSEMBLE concept is quite useful in providing decision makers with guidance in the event of an accidental atmospheric release. Providing timely information to a decision maker in such events is crucial in consequence assessment. The examples depicted in Figs. 2 and 3 are valuable in that they effectively communicate model uncertainty. These differences are a function of different inputs or different model physics assumptions.

The SRNL uses a prognostic atmospheric numerical model (RAMS) to provide automated forecasts of meteorological conditions in Europe, while a Lagrangian particle dispersion model (LPDM) simulates the transport effects. The RAMS/LPDM modeling system is versatile enough to handle variable spatial scales such as discussed in this paper.

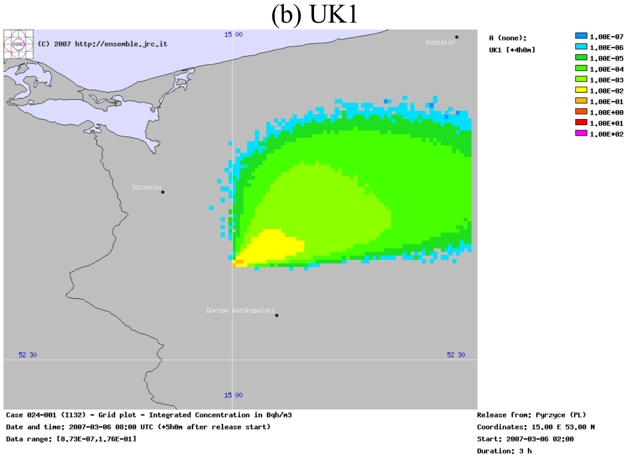
However, in a real emergency, eight-hour delays like that experienced with Exercise #024 (see Table I) would not be tolerable. Nested grids had to be incorporated into the SRNL modeling domain to account for fine-scale features necessary to provide output at 0.02º horizontal resolution.

At present, the necessary computing facilities are not available to dedicate to high-resolution simulations covering the majority of Europe. The SRNL system is adequate for long-range transport, but is currently incapable of modeling the short-range transport in a timely manner. Nevertheless, these exercises are useful to the modeling community and SRNL. The exercises allow modelers and responders to improve their methodology for generating and interpreting results.

(a) US1



(b) UK1



(c) GR2

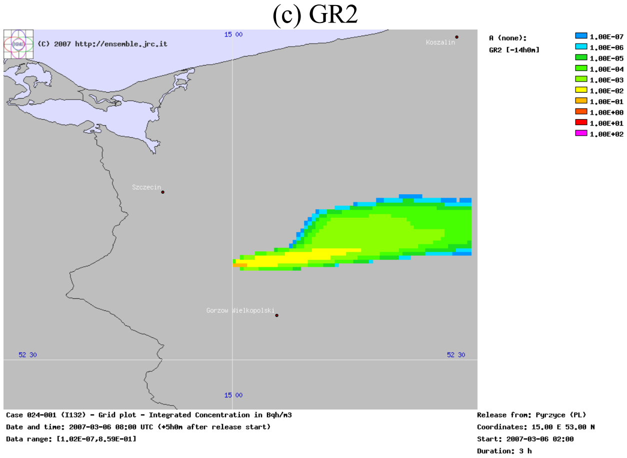


Figure 3: Plots of integrated surface concentration for Exercise #024 for ^{132}I at a time of 08 UTC, 06 March. Colors denote different orders of magnitude in concentration intensity.

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REFERENCES

1. S. Galmarini, R. Bianconi, R. Bellasio, G. Graziani, "Forecasting the consequences of accidental releases of radionuclides in the atmosphere from ensemble dispersion modeling," *J. Environ. Radioactivity*, **57**, pp. 203-219 (2001).

2. W. R. Cotton et al., "RAMS 2001: Current status and future directions," *Meteorol. Atmos. Phys*., **82**, pp. 5-29 (2002).

3. H. C. Davies, "A lateral boundary formulation for multi-level prediction models," *Quart. J. Roy. Met. Soc.*, **102**, pp. 405-418 (1976).

4. M. Uliasz, "The atmospheric mesoscale dispersion modeling system," *J. Appl. Meteor.*, **32**, pp. 139-149 (1993).

5. F. A. Gifford, "Horizontal diffusion in the atmosphere: a Lagrangian-dynamical theory," *Atmos. Environ.*, **16**, pp. 505-512 (1982).